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Estimation of Surface Water Potential in Manokwari Regency Using Remote Sensing Data

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ABSTRACT

Water availability is major issue in Manokwari Regency, and information on its surface water potential has not yet been available. This study aimed to estimate the surface water potential in Manokwari using remote sensing data, namely EROS Visible Infrared Imaging Radiometer Suite (eVIIRS) images acquired in August–September 2024 and Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data from 1981–2023. The analysis consisted of three main stages: data inventory, runoff coefficient estimation, and surface water potential calculation using the Melchior method. The results showed that the surface water potential in Manokwari was 2,018.70 m³/s at 99% probability and 4,148.60 m³/s at 80% probability. These values exceed the 2024 water demand, indicating that Manokwari is in a surplus water condition. The findings demonstrate the usefulness of satellite-based rainfall and land cover data for hydrological assessments in areas with limited ground observation stations.

1. INTRODUCTION

Clean water is a basic human need, making the availability of clean, safe water for health essential. The government continues to strive to ensure the availability of clean, safe water for the public. These efforts are outlined in several regulations, including Law No. 17 of 2019 concerning Water Resources, Government Regulation No. 121 of 2015 concerning Water Resources, and Government Regulation No. 122 of 2015 concerning Drinking Water Supply Systems.

Clean water availability is a significant issue in Manokwari Regency. According to Statistics Indonesia (BPS), access to improved drinking water for the population of West Papua Province in 2023 was approximately 81.57%, still below the national average of 91.72% (Badan Pusat Statistik, 2024a). Meanwhile, 83.27% of Manokwari Regency residents have access to safe drinking water (Badan Pusat Statistik, 2024b), with 5.36% coming from pumped water, 39.44% from bottled water, 32.00% from well water, 18.69% from springs, and 4.51% from other sources (surface water and rainwater).

To date, no data is available on the water potential of Manokwari Regency. This is due to the lack of discharge measurements in the main rivers in Manokwari Regency. Furthermore, the limited number of rainfall stations/climate stations in Manokwari Regency hinders surface water potential analysis. Currently, there is only one climate station in Manokwari Regency, the Rendani station (BMKG, 2018). The World Meteorological Organization (WMO) recommends that weather or climate observation stations can represent an area of 100 km^2–1000 km^2 (World Meteorological Organization, 2010). If referring to the World Meteorological Organization (WMO) recommendation that weather or climate observation stations can represent an area of 100 km^2–1000 km^2 (World Meteorological Organization, 2010), then Manokwari Regency which has an area of ± 2,762.89 km^2 (Badan Pusat Statistik, 2024c) ideally has a minimum of 3 climate stations.

Remote sensing-based rainfall data is now available and can be used to analyze surface water potential in Manokwari Regency. This data can be used as an alternative solution to obtain rainfall data due to the limited availability of climate stations with a high level of spatial representation. Some examples of rainfall data recorded by satellite include: TRMM (Tropical Rainfall Measuring Mission), CHIRPS (Climate Hazards Group Infrared Precipitation with Stations), GPM (Global Precipitation Measurement), GSMap (Global Rainfall Map), CMORPH (CPC Morphing Technique), CHOMPS (CICS High-Resolution Optimally Interpolated Microwave Precipitation from Satellites), Daymet (Daily Surface Weather and Climatological Summaries), GPCC (Global Precipitation Climatology Center), GPCP (Global Precipitation Climatology Project), PERSIANN-CDR (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Climate Data Record), APHRODITES (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation), and CELSA (The Climatologies at high resolution for the Earth's land surface) (National Center for Atmospheric Research Staff, 2020).

Several previous studies have shown that rainfall data observed using remote sensing technology has good accuracy compared to data recorded at climate stations and Automatic Weather Stations (AWS). Research conducted by Faisol *et al*. (2020) showed that CHIRPS was quite accurate in estimating daily rainfall in East Java, with a deviation rate of 11.41% compared to data observed at climate stations. Furthermore, Faisol *et al*. (2019) tested the accuracy of GPM satellite imagery in estimating rainfall in West Papua Province, and the results showed that GPM satellite imagery had a 68% accuracy in estimating daily rainfall in West Papua Province. Budiyono & Faisol (2021) reported that CHIRPS had a deviation rate of 2.75 mm in estimating daily rainfall in West Papua Province. Research conducted by Suryanto & Faisol (2022) showed that TerraClimate had a 12.2% bias in estimating daily rainfall in West Kalimantan Province. The use of remote sensing data to estimate surface water potential has been carried out by several researchers in Indonesia. Aristiwijaya (2015) used Landsat 8 satellite imagery to identify potential water sources in Bojonegoro Regency. Radhika *et al*. (2017) utilized TRMM data to identify surface water availability in Indonesia. Willy *et al*. (2020) analyzed water availability in the Duriangkang Dam in Batam using TRMM data. Gampo *et al*. (2023) used TRMM data to analyze water availability in the Melawi sub-watershed in West Kalimantan. Herdiansyah *et al*. (2022) used CHIRPS data to estimate water potential in Semarang Regency. The use of remote sensing data to estimate water potential has never been done in Manokwari Regency. Based on these conditions, this study aims to estimate water potential in Manokwari Regency by utilizing CHIRPS and EROS Visible Infrared Imaging Radiometer Suite (eVIIRS) data to obtain information on the amount of surface water in Manokwari Regency. CHIRPS provides daily, 5-day, 10-day, monthly, and 3-month rainfall data at a spatial resolution of 5 km (Funk *et al*., 2014), and eVIIRS provides 7-day and 10-day Normalized Difference Vegetation Index (NDVI) data at a spatial resolution of 500–1,000 m (Earth Resources Observation and Science (EROS) Center, 2021). This research is the first to integrate eVIIRS and CHIRPS to estimate water potential in Manokwari Regency.

2. MATERIALS AND METHODS

2.1. Research Location

This research was conducted in Manokwari Regency, West Papua Province with location shown in Figure 1.

2.2. Data and Data Sources

The data used in this study were the EROS Visible Infrared Imaging Radiometer Suite (eVIIRS), Climate Hazards Group Infrared Precipitation with Stations (CHIRPS), and watershed boundary maps. eVIIRS was obtained from https://earthexplorer.usgs.gov, CHIRPS was obtained from https://data.chc.ucsb.edu/products/CHIRPS/v3.0/, watershed boundary maps were obtained from the Ministry of Forestry, and topographic maps and river network maps were obtained from the Geospatial Information Agency (BIG) at https://tanahair.indonesia.go.id/portal-web/.

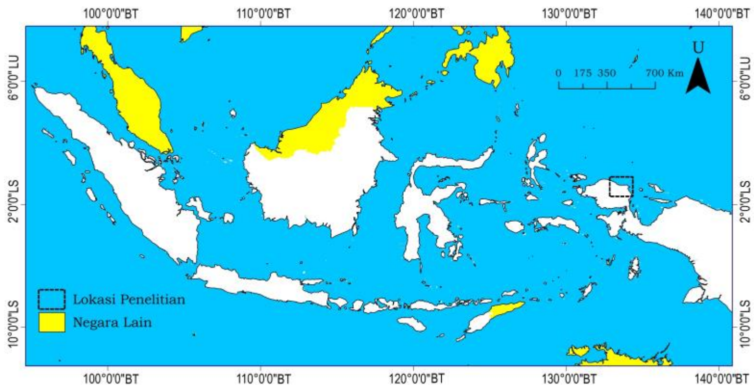


Figure 1. Research location.

2.3. Research Stages

In general, this research was conducted in three main stages: Data inventory, runoff analysis, and surface water potential analysis. The data inventory was conducted from July to September 2024. This stage aimed to collect eVIIRS data recorded in August–September 2024, CHIRPS data recorded in 1981–2023, watershed boundary maps, topographic maps, and river network maps. The runoff analysis stage aimed to generate runoff coefficient (α) information based on the Normalized Difference Vegetation Index (NDVI) data obtained from eVIIRS. Finally, the surface water potential analysis aimed to analyze surface water potential in Manokwari Regency. The surface water potential analysis was calculated based on watershed characteristics, CHIRPS rainfall recordings, and surface flow. Surface water potential was calculated for each major watershed in Manokwari Regency. The stages in this research are presented in Figure 2.

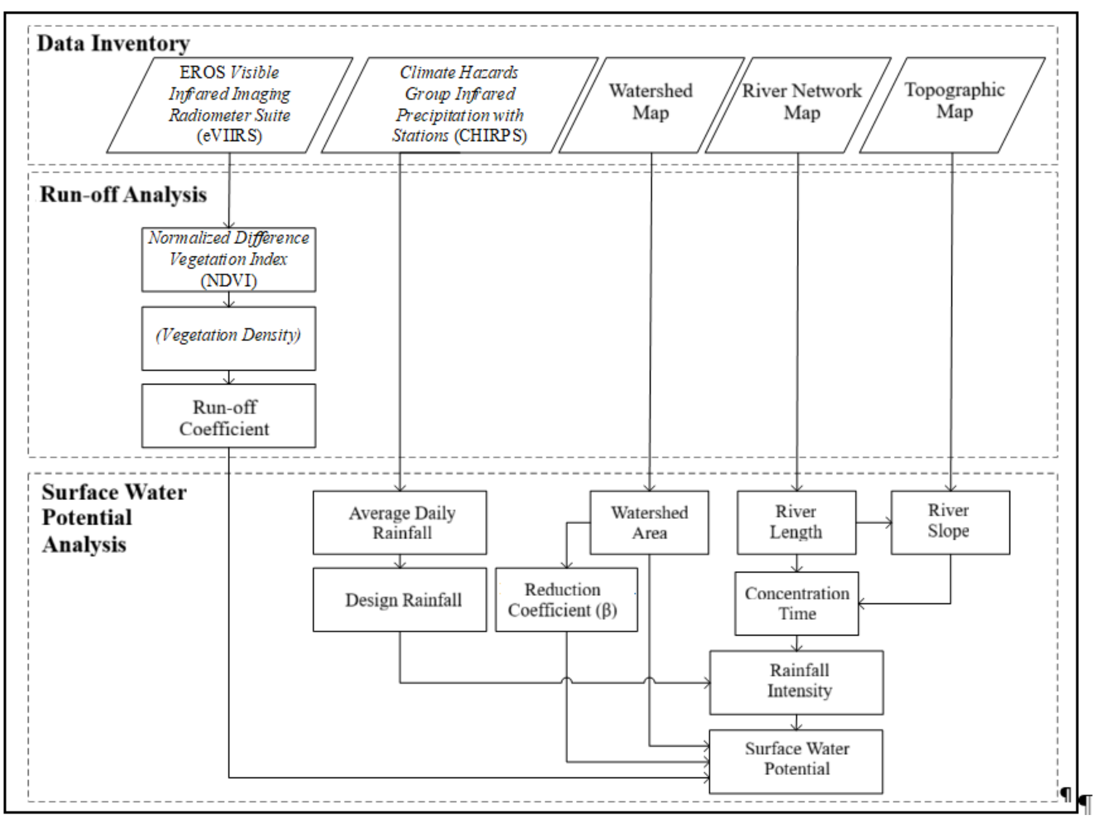


Figure 2. Research flowchart.

2.4. Calculation Method

1. Runoff

The runoff coefficient (α) was calculated using the following equation (Suhardi & Entin, 2019; Suhardi *et al*., 2020):

$$\alpha = 1 - \frac{VD}{100} \tag{1}$$

where α is runoff coefficient, and VD = plant density. The plant density (VD) was estimated using the NDVI (Normalized Difference Vegetation Index) approach with the following equation (Suhardi *et al*., 2020):

$$VD = 37.705\, NDVI - 1.596 \tag{2}$$

NDVI was calculated based on near-infrared band reflectance value (ρ_{NIR}) and red band reflectance value (ρ_{RED}) using the following equation (Liu & Mason, 2009):

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{3}$$

2. Surface water potential analysis

Surface water potential was analyzed using the Melchior method as the following (Faisol, 2020; Kamiana, 2011):

$$Q = \alpha \cdot \beta \cdot I \cdot A \tag{4}$$

where Q is river discharge (m^3/second); α is runoff coefficient; β is reduction coefficient; I is rainfall intensity (m^3/second/km^2); and A is watershed area (km^2).

The reduction coefficient (β) was calculated using the watershed area approach with the following equation (Badan Standardisasi Nasional, 2016; Faisol, 2020; Kamiana, 2011):

$$A = \left(\frac{1970}{\beta - 0.12}\right) - 3960 + 1720\,\beta \tag{5}$$

where A is watershed area (km^2).

Rainfall intensity (I) in the Melchior method was calculated as the following (Kamiana, 2011; Faisol, 2020):

$$I = \frac{10\,\beta\, R_{24}}{36\, t_c} \tag{6}$$

where I is rainfall intensity at the time of concentration ($m^3 \cdot s^{-1} \cdot km^{-2}$), t_c is concentration time (h), and R_{24} is the design rainfall (mm/day) which was analyzed using a normal distribution with the following equation (Faisol, 2020):

$$R_{24} = \mu + K_t \sigma \tag{7}$$

where R_{24} is design rainfall at the return period t year (mm/day); σ is standard deviation of the average daily rainfall (mm/day); μ is average daily rainfall (mm/day); and K_t is reduction variable. The reduction variable (K_t) for each return period was presented in Table 1 (Faisol, 2020).

The concentration time (tc) is the time required from the furthest point to reach the outlet. The time of concentration can be calculated using the following Kirpich equation (Kamiana, 2011; Badan Standardisasi Nasional, 2016; Thompson, 2006; Hingray *et al*., 2015; Mimikou *et al*., 2016; Faisol, 2020):

$$t_c = 0.01947\, L^{0.77} S^{-0.385} \tag{8}$$

where L is length of the main river (m), and S is slope of the main river that was calculated from H (difference in elevation of the main river, i.e., the difference in elevation between the furthest point and the outlet) using the following equation (Mimikou *et al*., 2016; Faisol, 2020):

$$S = H/L \tag{9}$$

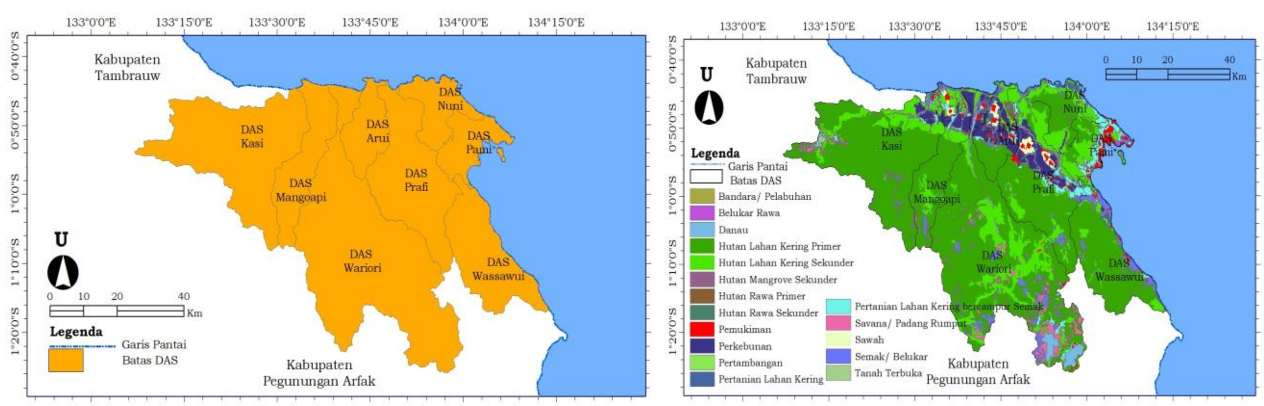
Table 1. Reduction variables in a Normal Distribution.

Return Period (Years)	Probability	Reduction Variable
1.00	0.99	-3.05
1.25	0.80	-0.84
1.67	0.60	-0.25
2.00	0.50	0
2.50	0.40	0.25
5.00	0.20	0.84
10.00	0.10	1.28
20.00	0.05	1.64
50.00	0.02	2.05
100.00	0.01	2.33

3. RESULTS AND DISCUSSION

According to the watershed map released by the Ministry of Environment and Forestry, Manokwari Regency has eight main watersheds: the Nuni Watershed, the Wariori Watershed, the Mangoapi Watershed, the Prafi Watershed, the Wassawui Watershed, the Kasi Watershed, the Arui Watershed, and the Pami Watershed. Interpretation of the river network map and topography reveals that the watersheds in Manokwari Regency range in length from approximately 20.28 km to approximately 89.63 km, with slopes ranging from approximately 0.0012 to 0.0897. The characteristics and distribution of watersheds in Manokwari Regency are presented in Figure 3a and Table 2. The land cover conditions in Manokwari Regency are presented in Figure 3b.

Based on analysis of EROS Visible Infrared Imaging Radiometer Suite (eVIIRS) satellite imagery recorded from August to September 2024, the vegetation index (NDVI) values in eight major watersheds in the Regency ranged from -0.2 to 1, with an average value of 0.85. The negative NDVI values were caused by cloud cover in the area (Sergieieva, 2025). The distribution of NDVI in Manokwari Regency, based on eVIIRS analysis from August to September 2024, is presented in Table 3 and Figure 4a.



(a) (b)

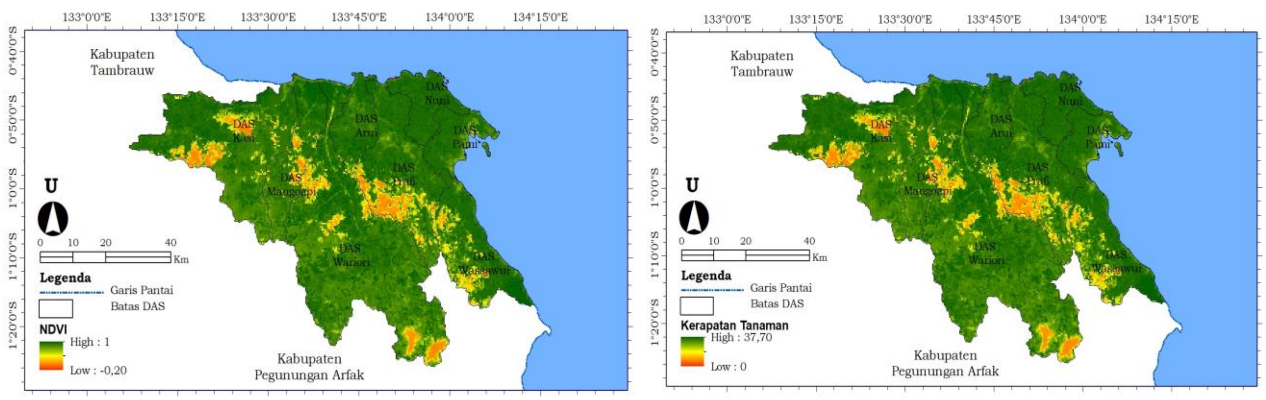
Figure 3. (a) Distribution of Watersheds in Manokwari Regency, and (b) Land cover map of Manokwari Regency.

Table 2. Characteristics of watersheds in Manokwari Regency

Watershed	Area (km²)	Main River Length (km)	Main River Slope
Nuni	231	24.27	0.0021
Wariori	1,635	89.63	0.0137
Mangoapi	374	57.89	0.0453
Prafi	676	59.49	0.0143
Wassawui	500	28.99	0.0897
Kasi	980	45.23	0.0116
Arui	232	23.65	0.0042
Pami	216	20.28	0.0012

Table 3. Vegetation characteristics of watersheds in Manokwari Regency

Watershed	Average Vegetation Index (NDVI)	Average Plant Density (VD)	Average Runoff Coefficient (α)
Nuni	0.94	33.85	0.66
Wariori	0.83	29.70	0.70
Mangoapi	0.83	29.70	0.70
Prafi	0.78	27.81	0.72
Wassawui	0.82	29.32	0.71
Kasi	0.81	28.95	0.71
Arui	0.91	32.72	0.67
Pami	0.90	32.34	0.68



(a) (b)

Figure 4. (a) Vegetation index, and (b) Vegetation density in watersheds in Manokwari Regency, based on analysis of eVIIRS (EROS Visible Infrared Imaging Radiometer Suite) satellite imagery recorded from August to September 2024.

The high vegetation index values in several watersheds in Manokwari Regency are due to the land cover still being dominated by forest. This is relevant to the land cover map released by the Ministry of Environment and Forestry (KLHK), which shows that land cover in Manokwari Regency is still dominated by forests (Ratnasari & Tosiani, 2022). Vegetation density (VD) in Manokwari Regency, based on NDVI analysis, ranges from 0 to 37.70, with an average value of 30.55. The VD value approaches 0 due to cloud cover in the area. The distribution of VD in Manokwari Regency, based on NDVI analysis recorded in August-September 2024, is presented in Figure 4b and Table 3. The runoff coefficient (α) in the Regency, based on NDVI analysis of data recorded in August–September 2024, ranged from 0.62 to 1.08. The distribution of runoff coefficients (α) in Manokwari Regency is presented in Figure 5 and Table 3.

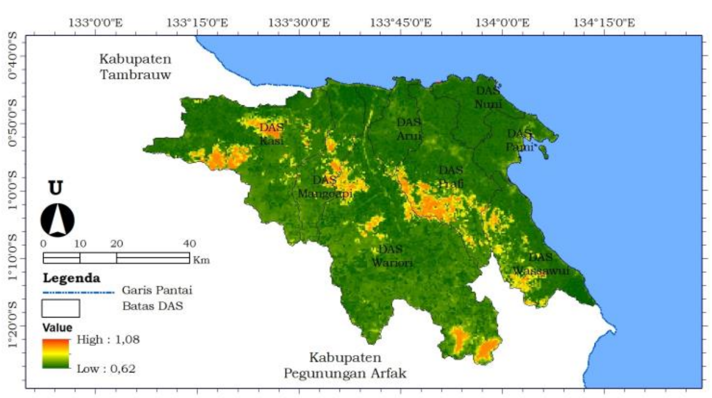


Figure 5. Runoff coefficient in watersheds in Manokwari Regency based on analysis of EROS Visible Infrared Imaging Radiometer Suite (eVIIRS) satellite imagery recorded in August–September 2024.

The concentration time (t_c) in the Manokwari watershed ranges from 2.24 to 11.01 hours, with an average concentration time of 7.07 hours. The reduction coefficient (β) ranges from 1.70 to 2.83, with an average value of 2.04. The concentration time and reduction coefficient in the eight main watersheds in Manokwari Regency are presented in Table 4.

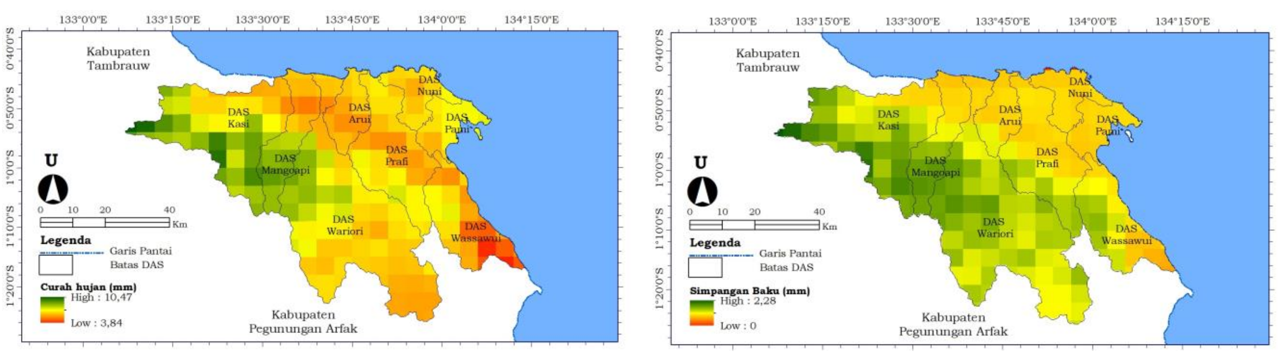
Table 4. Hydraulic characteristics of watersheds in Manokwari Regency

Watershed	Reduction Coefficient (β)	Time of Concentration (tc) Minutes	Time of Concentration (tc) Hours
Nuni	1.72	498	8.29
Wariori	2.83	661	11.01
Mangoapi	1.86	298	4.96
Prafi	2.12	474	7.90
Wassawui	1.98	134	2.24
Kasi	2.36	416	6.94
Arui	1.72	373	6.22
Pami	1.70	537	8.96

Table 5. Rainfall characteristics of watersheds in Manokwari Regency based on CHIRPS data records (1981–2023).

Watershed	Average Daily Rainfall (μ) (mm)	Standard Deviation (σ) (mm)	Design Rainfall (R_{24}) (mm)	
			Probability 99%	Probability 80%
Nuni	6.40	0.89	3.69	5.65
Wariori	6.74	1.42	2.41	5.55
Mangoapi	7.33	1.37	3.15	6.18
Prafi	6.42	1.13	2.97	5.47
Wassawui	5.74	1.14	2.26	4.78
Kasi	7.90	1.52	3.26	6.62
Arui	5.97	0.97	3.01	5.16
Pami	6.93	0.89	4.22	6.18

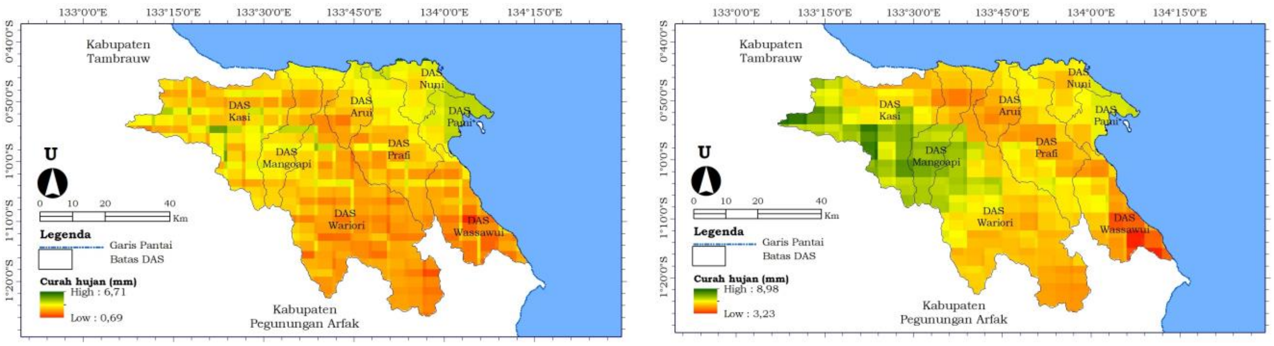
The average daily rainfall in Manokwari Regency, based on CHIRPS data analysis from 1981 to 2024, was 6.87 mm with a standard deviation of 1.29 mm. This is relevant to research conducted by Rakhim & Pattipeilohy (2022), which found that the average daily rainfall in Manokwari Regency from 1991 to 2020 was 6.57 mm. The distribution of rainfall across the eight main watersheds in Manokwari Regency is presented in Table 5 and Figures 6.



(a) (b)

Figure 6. Distribution of (a) average daily rainfall, and (b) standard deviations of average daily rainfall across watersheds in Manokwari Regency based on CHIRPS data recorded from 1981 to 2023.

Based on the analysis using a normal distribution, daily rainfall with a 99% probability of occurrence in the Manokwari Watershed ranges from 0.69 mm to 6.71 mm, and daily rainfall with an 80% probability of occurrence ranges from 3.23 mm to 8.98 mm. The distribution of daily rainfall in eight major watersheds in Manokwari Regency, with a 99% and 80% probability of occurrence, is presented in Table 5 and Figure 7.



(a) (b)

Figure 7. Graph of daily rainfall distribution in watersheds in Manokwari Regency based on CHIRPS data recorded from 1981 to 2024: (a) with a 99% probability of occurrence, and (b) with a 80% probability of occurrence,

Rainfall intensity in Manokwari Regency based on CHIRPS data analysis from 1981 to 2023 is 0.28 $m^3 \cdot s^{-1} \cdot km^{-2}$ at a 99% probability of occurrence, and 0.54 $m^3 \cdot s^{-1} \cdot km^{-2}$ at an 80% probability of occurrence. Meanwhile, the surface water potential in Manokwari Regency is 2,018.70 m^3/s at a 99% probability of occurrence, and 4,148.60 m^3/second at an 80% probability of occurrence. The results of this study are quite relevant to the study conducted by Wihyawari (2014) that the water potential in the Wariori River (Wariori Watershed) is ±823.08 m^3/s based on measurement results. Research conducted by Duvvuri *et al*. (2024) shows that river discharge estimated from remote sensing data has a relative bias of 11%. Furthermore, research conducted by Bjerklie *et al*. (2018) showed that remote sensing data has an error of 13% in estimating river discharge, and research conducted by Masafu *et al*. (2023) showed that river discharge data estimated from remote sensing data has a difference of 15% compared to the measured data. Rainfall intensity and water potential in Manokwari Regency with a probability of occurrence of 99% and 80% based on the results of CHIRPS data analysis are presented in Table 6.

Table 6. Rainfall intensity and surface water potential in Manokwari Regency based on CHIRPS data records (1981–2023)

Watershed	**Rainfall Intensity** ($m^3 \cdot s^{-1} \cdot km^{-2}$)		**Water Potential (m^3/s)**	
	Probability 99%	**Probability 80%**	**Probability 99%**	**Probability 80%**
Nuni	0.21	0.33	55.91	85.75
Wariori	0.17	0.40	559.42	1.288.19
Mangoapi	0.33	0.64	160.85	315.38
Prafi	0.22	0.41	230.03	423.22
Wassawui	0.55	1.17	387.20	818.27
Kasi	0.31	0.63	507.48	1.029.76
Arui	0.23	0.40	62.24	106.54
Pami	0.22	0.33	55.57	81.50

Based on research by Osly *et al*. (2019), the water demand in Manokwari Regency is approximately 66,629,639 m^3/year, or 2.11 m^3/second. Therefore, the existing water potential in Manokwari Regency exceeds its water demand.

4. CONCLUSIONS AND RECOMMENDATIONS

This study successfully estimated the surface water potential in Manokwari Regency using integrated eVIIRS and CHIRPS data, the first remote sensing-based approach for this region. The surface water potential was recorded at 2,018.70 m^3/s with a 99% probability of occurrence and 4,148.60 m^3/s with an 80% probability of occurrence, values exceeding the water demand in 2024. These results indicate that Manokwari Regency is in a water surplus, offering significant potential to support agricultural development and domestic needs. Validation of these results with field measurement data is necessary to improve accuracy. Regional governments are advised to utilize this surface water potential information as a basis for water resource management planning, including irrigation infrastructure development and clean water supply. Furthermore, expanding the network of rainfall observation stations will strengthen the database for ongoing monitoring.

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